



## West Coast Ocean Energy Resources

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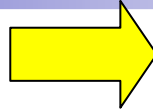
# Outline

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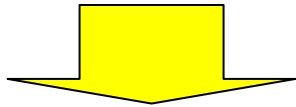
- 
- **Resource Assessment Fundamentals**
  - **Wave**
  - **Tidal**
  - **Wind**
  - **Confidence in Resource Estimates**
  - **Summary**

# What's extractable

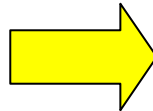
**Primary Hydrokinetic Resource**



**Can be measured and Modeled**

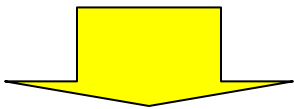


**Technology (Machine) Related Constraints**

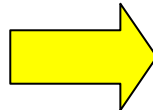


**Is Technology Specific**

- Machine Size
- Power Density
- Deployment Area Size
- Foundation
- Spacing Requirements



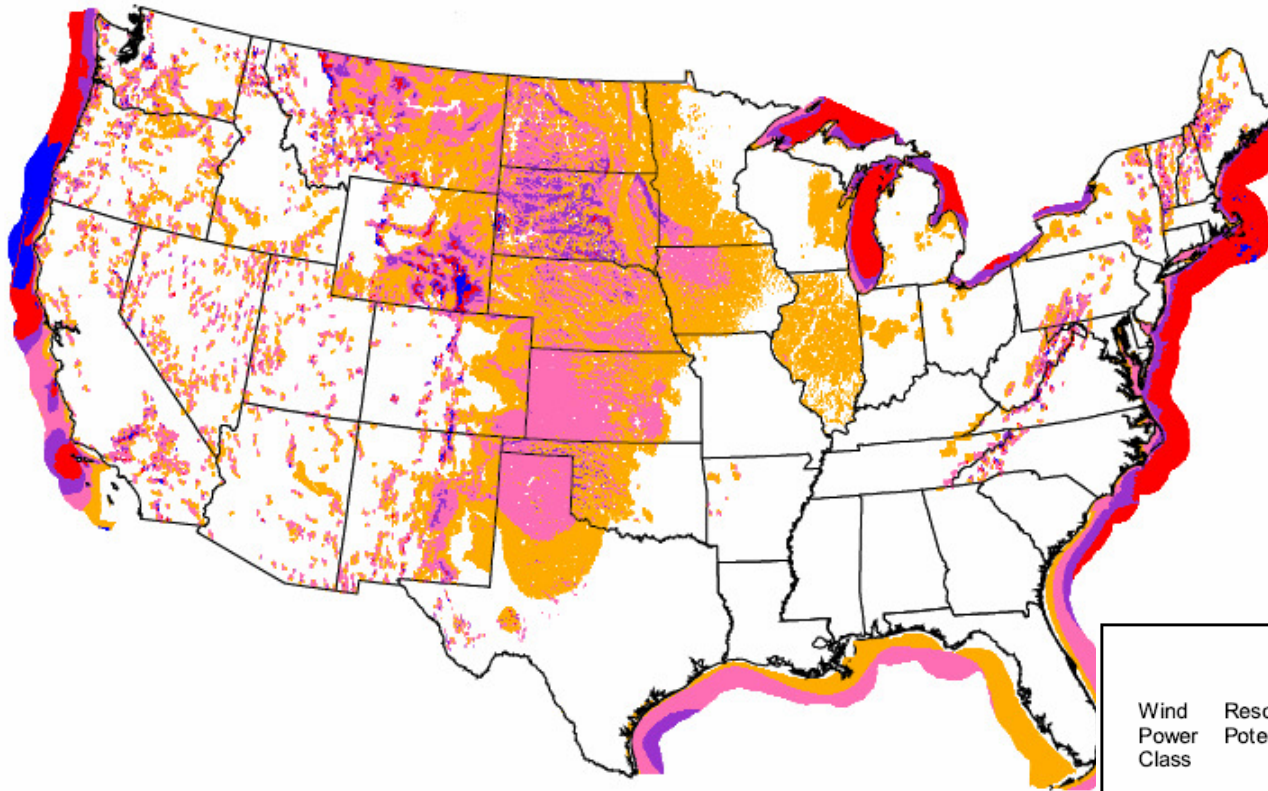
**Practical Constraints**



**Is Site Specific**

- Grid Interconnection
- Environmental Effects
- Competing Uses of Space
- NIMBY Issues

# Wind Energy – Power Density



Wind Power Densities in the US at 50m elevation (Source: NREL)

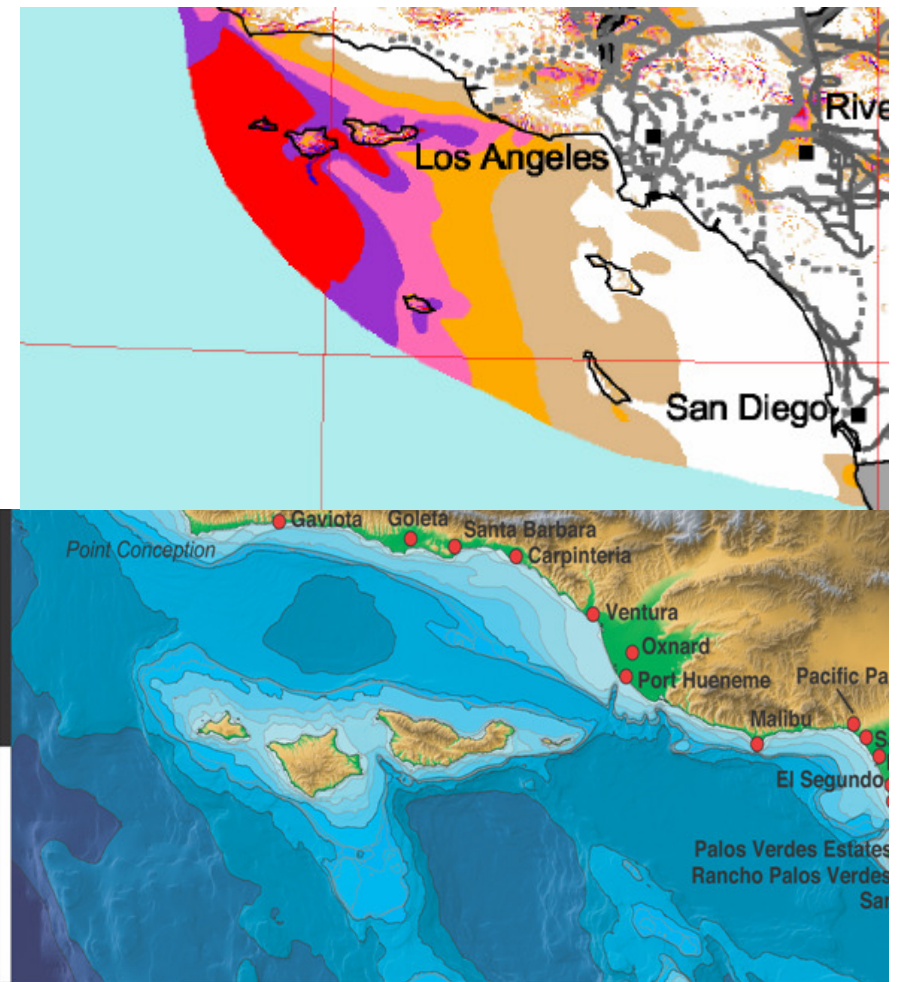
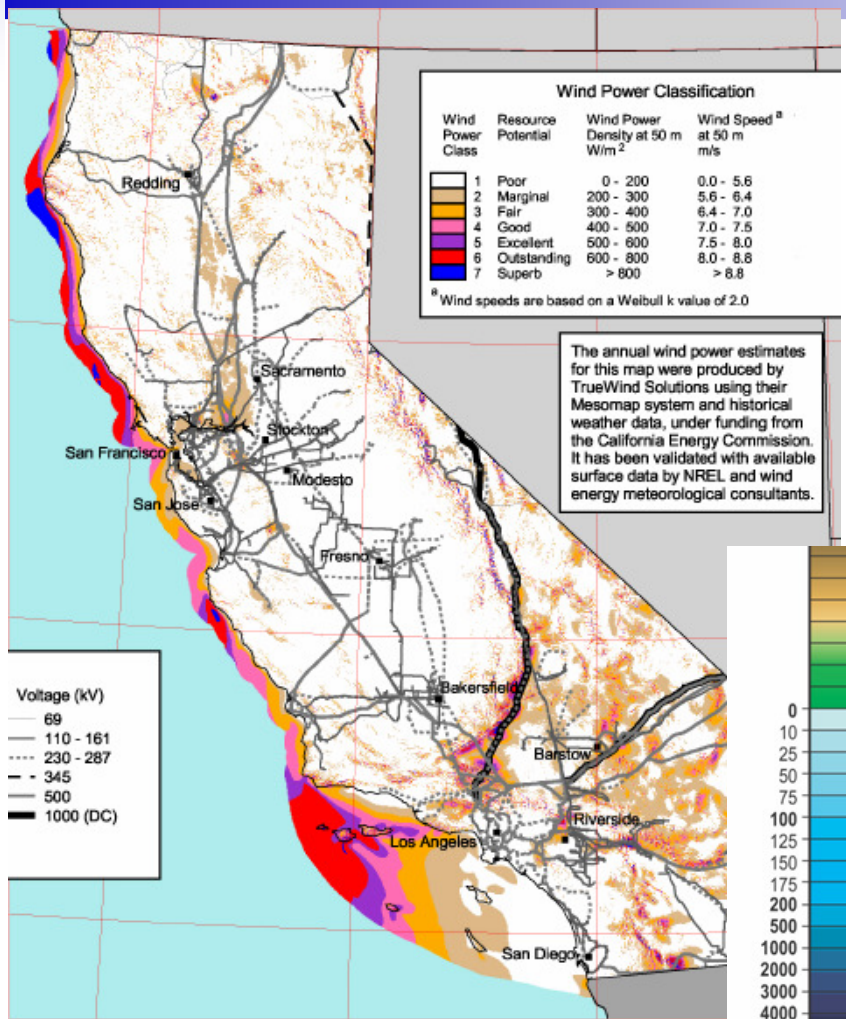
Weibull k value of 2.0

Area up to 50nm from shore

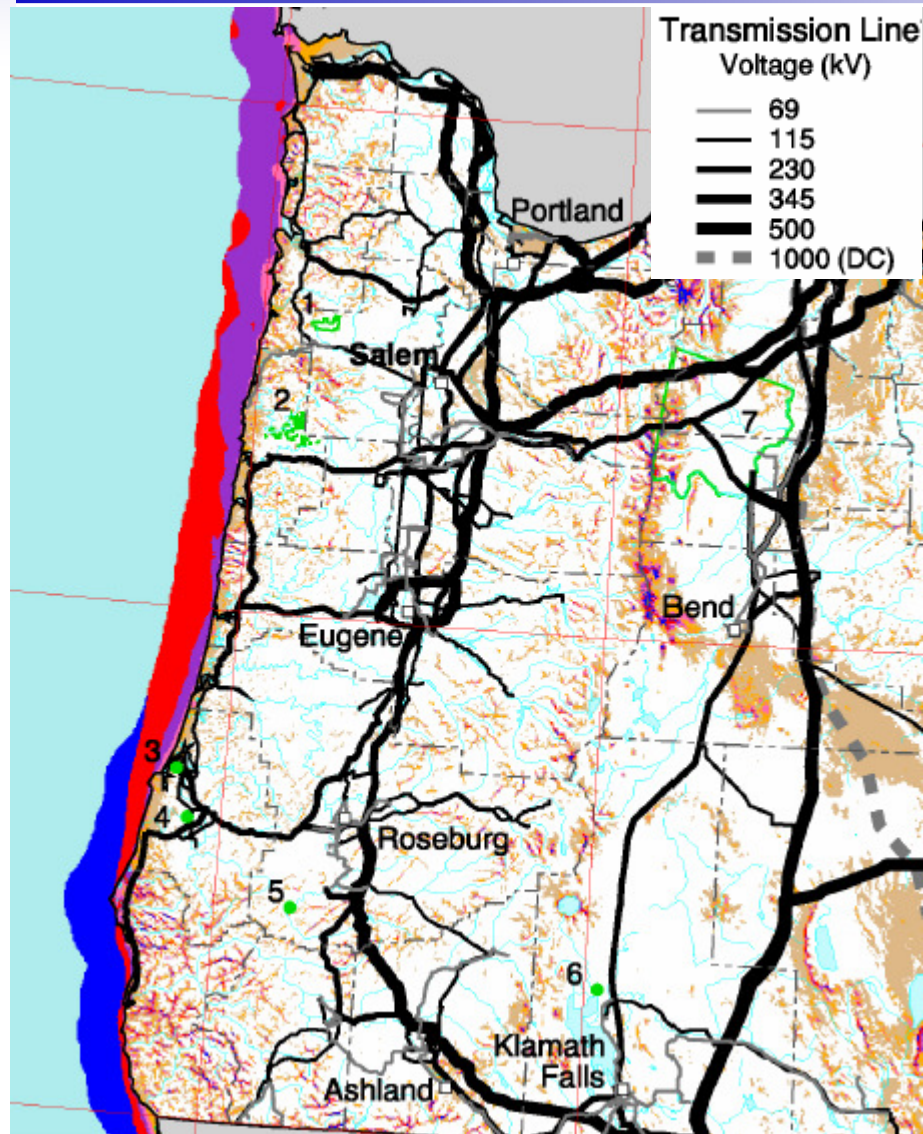
Wind Power Classification				
Wind Power Class	Resource Potential	Wind Power Density at 50 m $W/m^2$	Wind Speed <sup>a</sup> at 50 m m/s	Wind Speed <sup>a</sup> at 50 m mph
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

<sup>a</sup> Wind speeds are based on a Weibull k value of 2.0

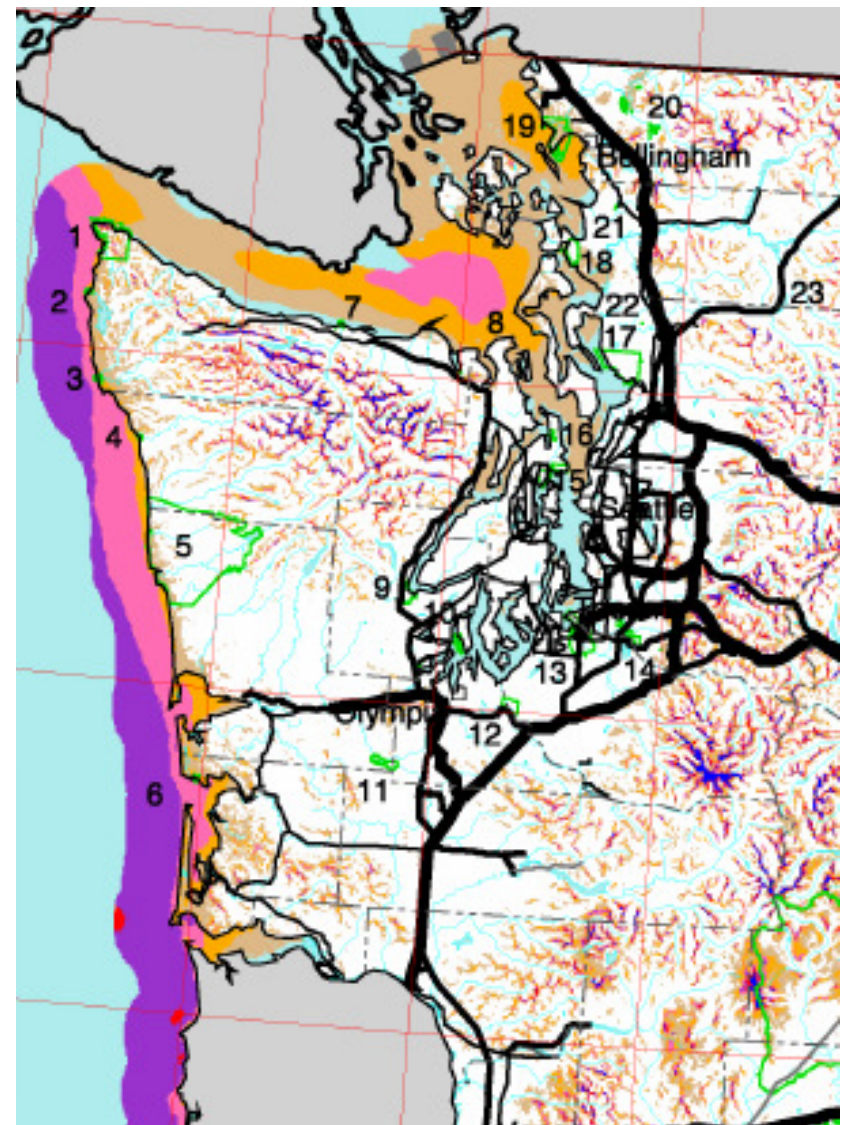
# Wind Resources – CA



# Wind Resources OR/WA



6

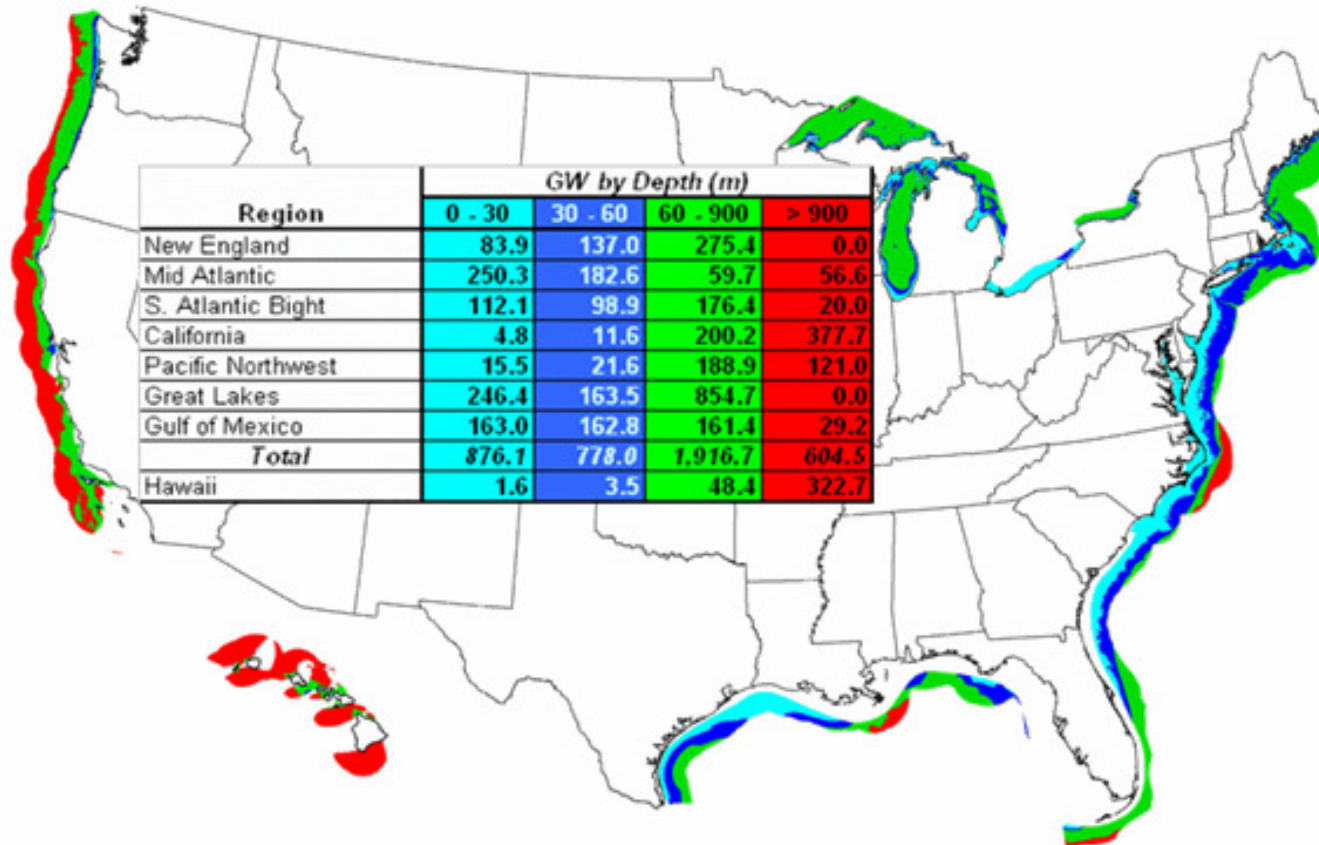


# Wind Extractable Resource

Installed capacity is limited by spacing assumptions for Wind Turbines to avoid rotor wake effects of one turbine impacting another turbine

- ⇒ NREL studies assumes a deployment density of 5MW per square kilometer
- ⇒ Capacity Factor of wind turbine depends on wind class (35%-50%)
- ⇒ Average Power Production per square mile is 1.75MW – 2.5MW
- ⇒ Annual; Energy Production per square mile is 15,000MWh/year – 22,000MWh/year

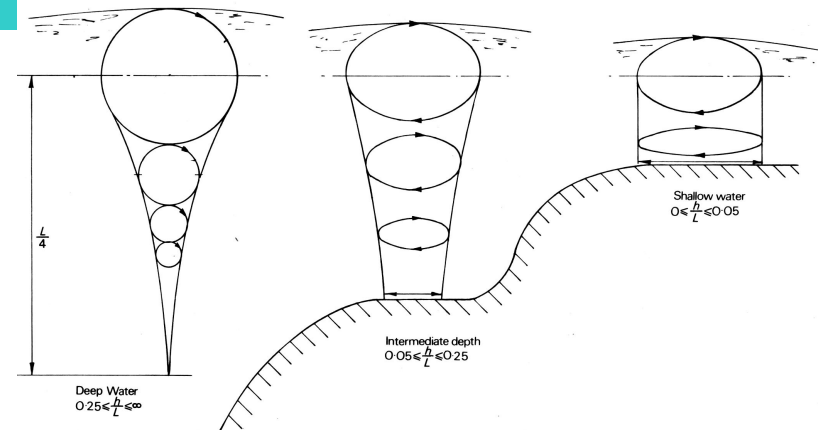
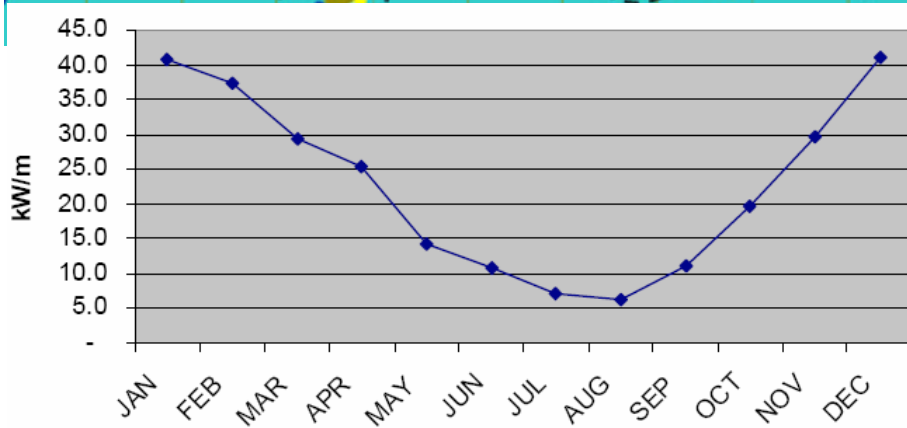
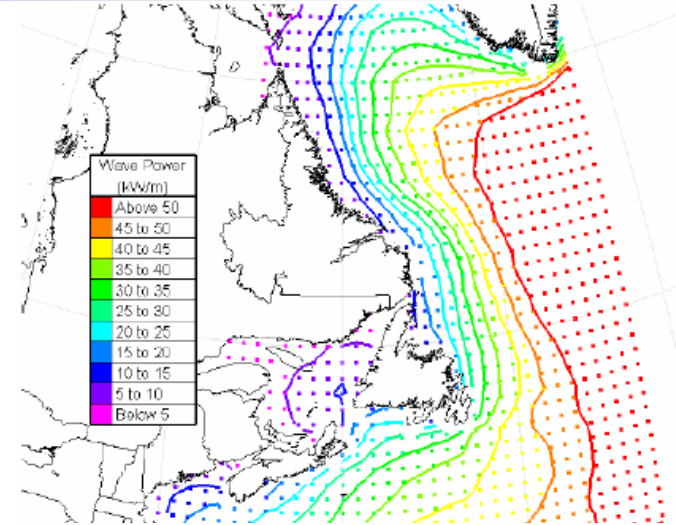
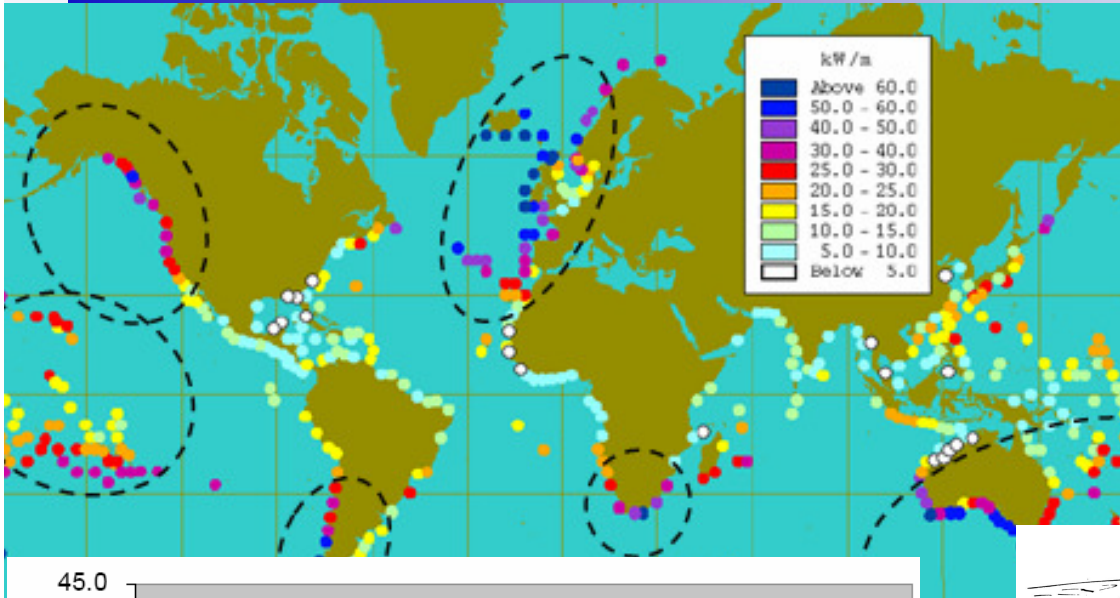
# Wind Extractable Resource by Water Depth



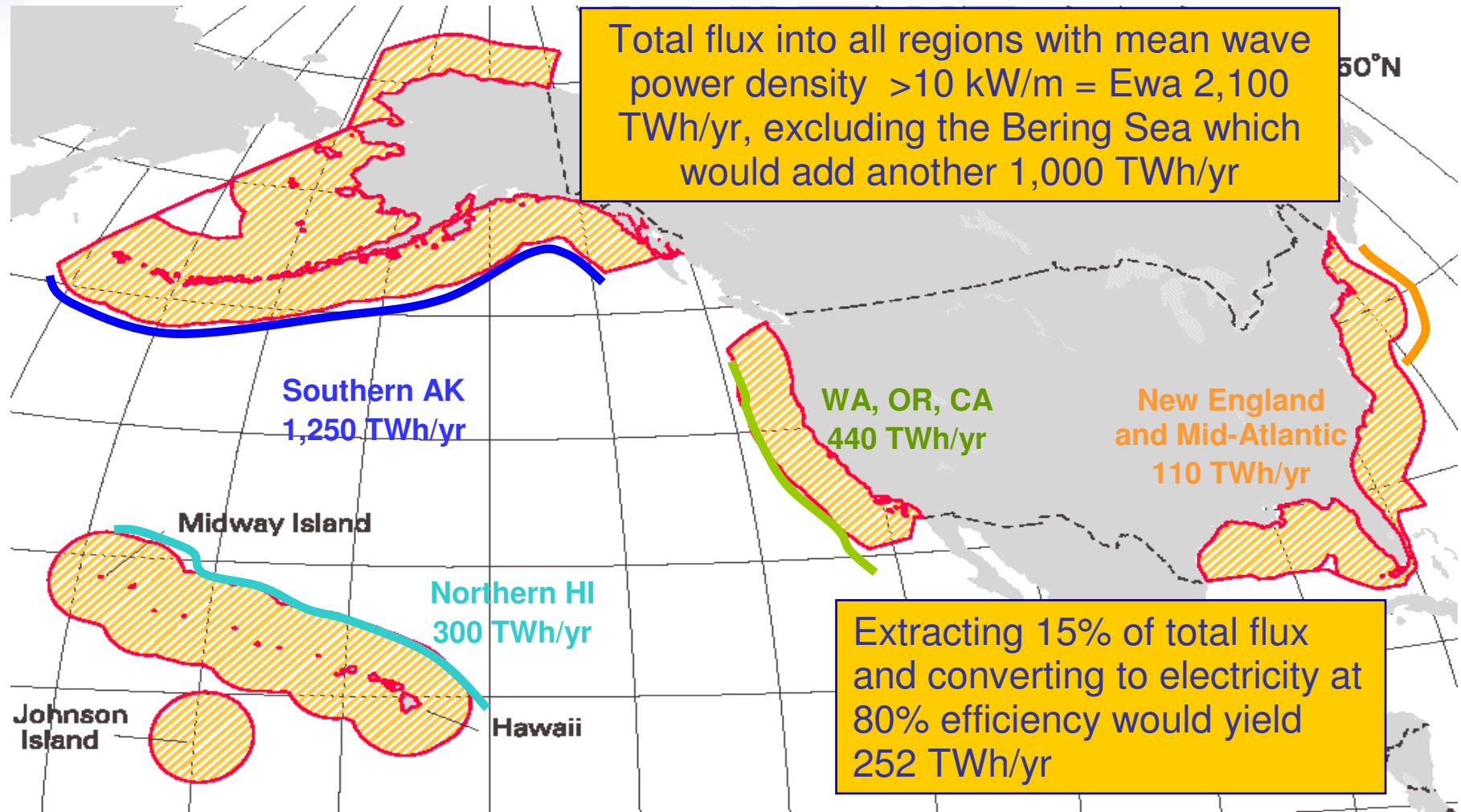
Bathymetry showing offshore wind resources Wind Class 4 and greater by depth (Source: internal report obtained from NREL)

Assumes: 5MW/km<sup>2</sup>

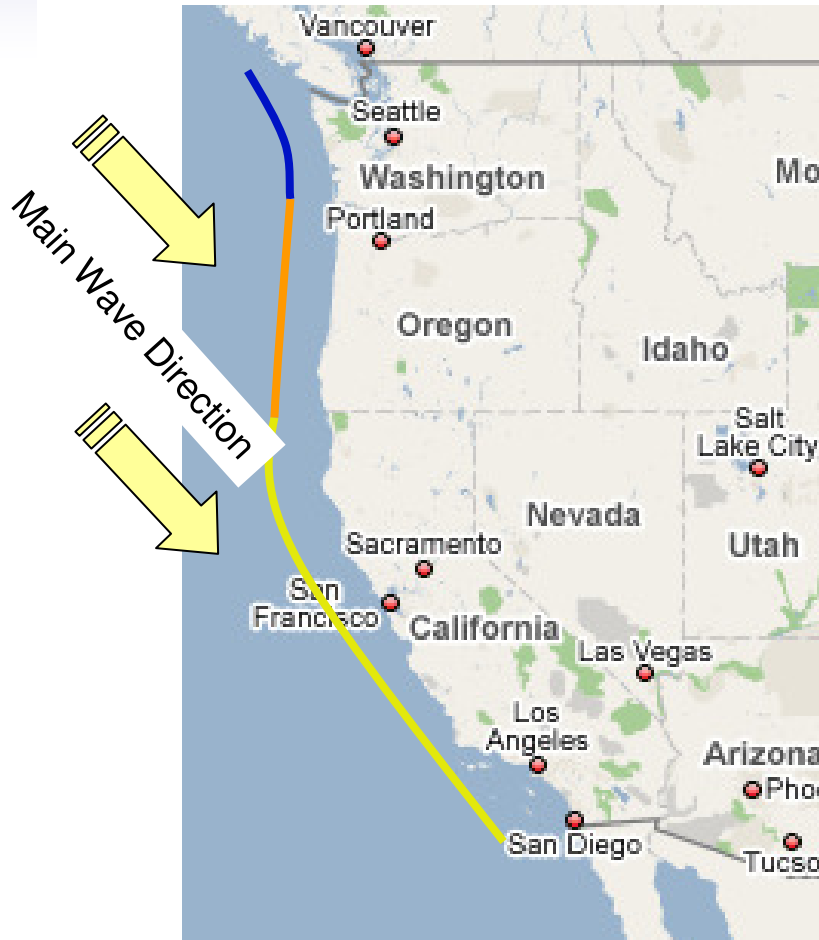
# Wave Energy Resource Characteristics



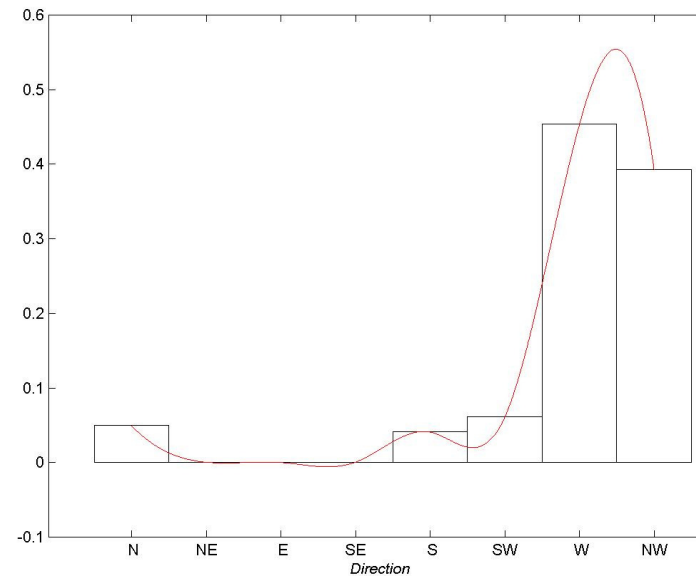
# U.S. Offshore Wave Energy Resources



# West Coast Offshore Wave Energy Resources



State	Coast Length	Pave (kW/m)	Ptotal (MW)
California	1200 km	30	36,000
Oregon	280 km	30	8,400
Washington	150 km	30	4,500
<b>Total</b>			<b>49,000</b>



# Extractable Resource

- Wide Range of Technologies introduce extraction potential uncertainties
- Deployment Water Depth: 50m
- Typical Distance from Shore: 2 – 5 miles (narrow continental shelf)
- Width of device array: < 1mile
- Modelled Extraction Efficiencies are technology dependent and range from 9% - 30%

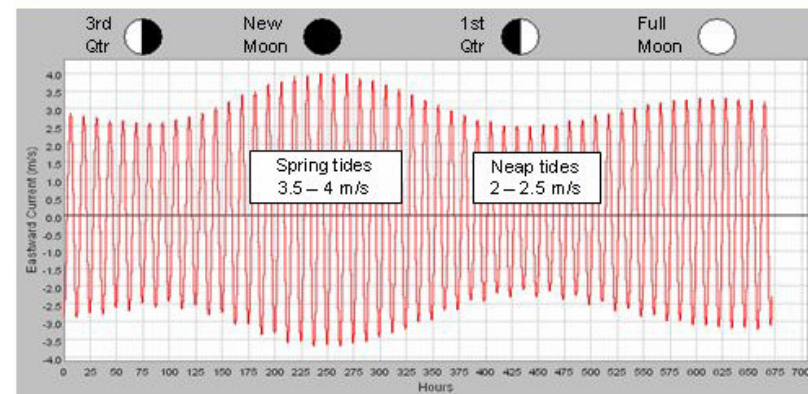
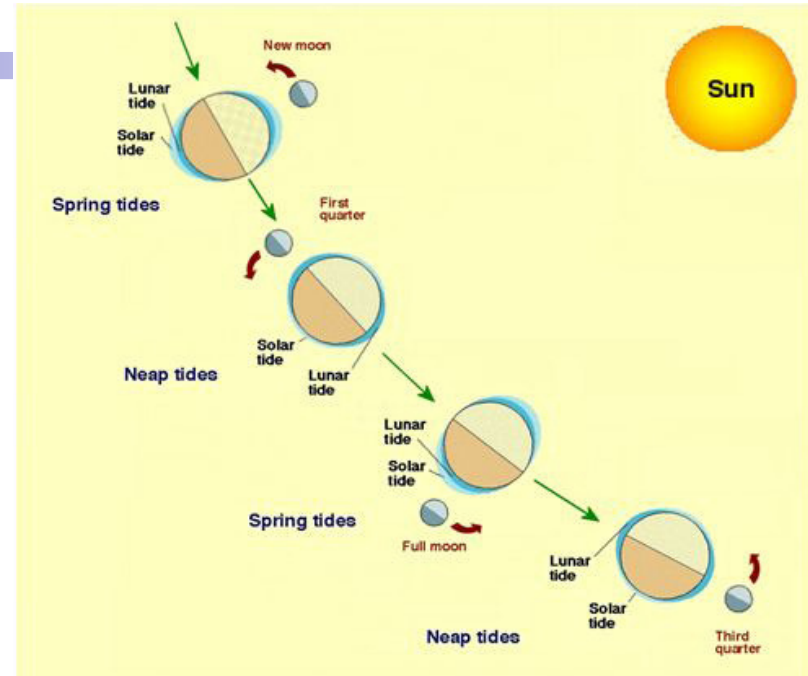
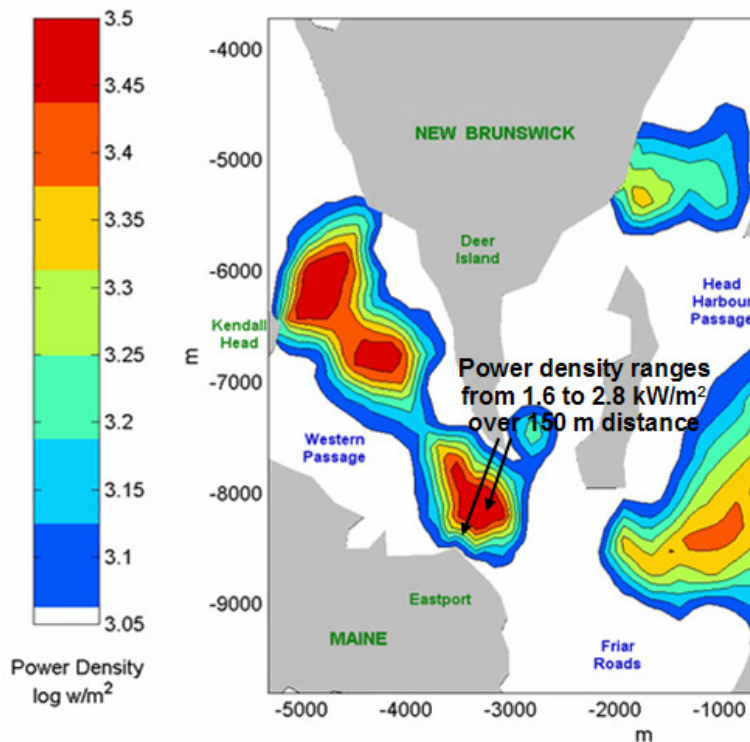
=> 15% is used for this study

Primary Average Power	49,000MW
Extractable Power (15%)	7,350MW
Annual Extractable Energy	64 TWh
West Coast Annual Electricity Demand	376 TWh
% of electric production from ocean wave	17%

# Tidal Energy Resource Characteristic

Highly Predictable

- Gravity Driven
- Very localized
- Power =  $f(v^3)$



# Tidal Current Energy

Many good sites  
in Alaska  
109 TWh/yr

## US TOTALS

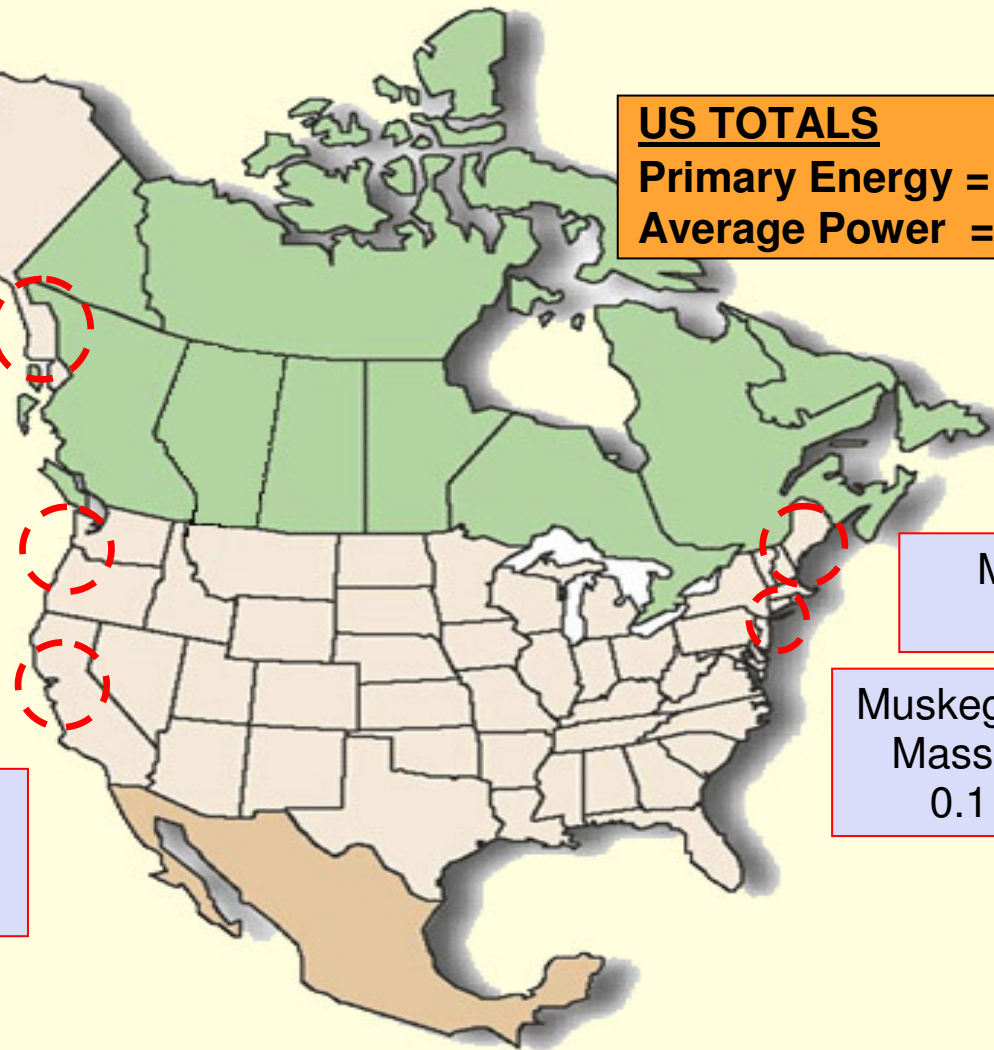
Primary Energy = 115 TWh/yr  
Average Power = 13,000 MW

Puget Sound WA  
8 sites  
4 TWh/yr

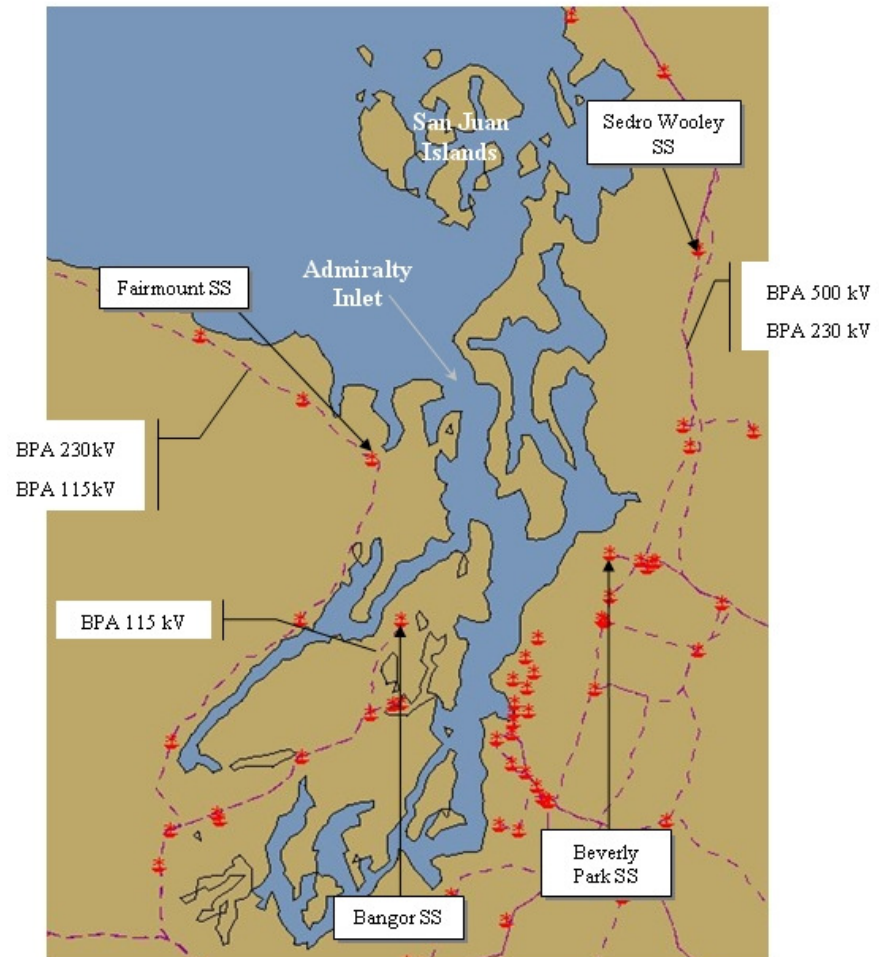
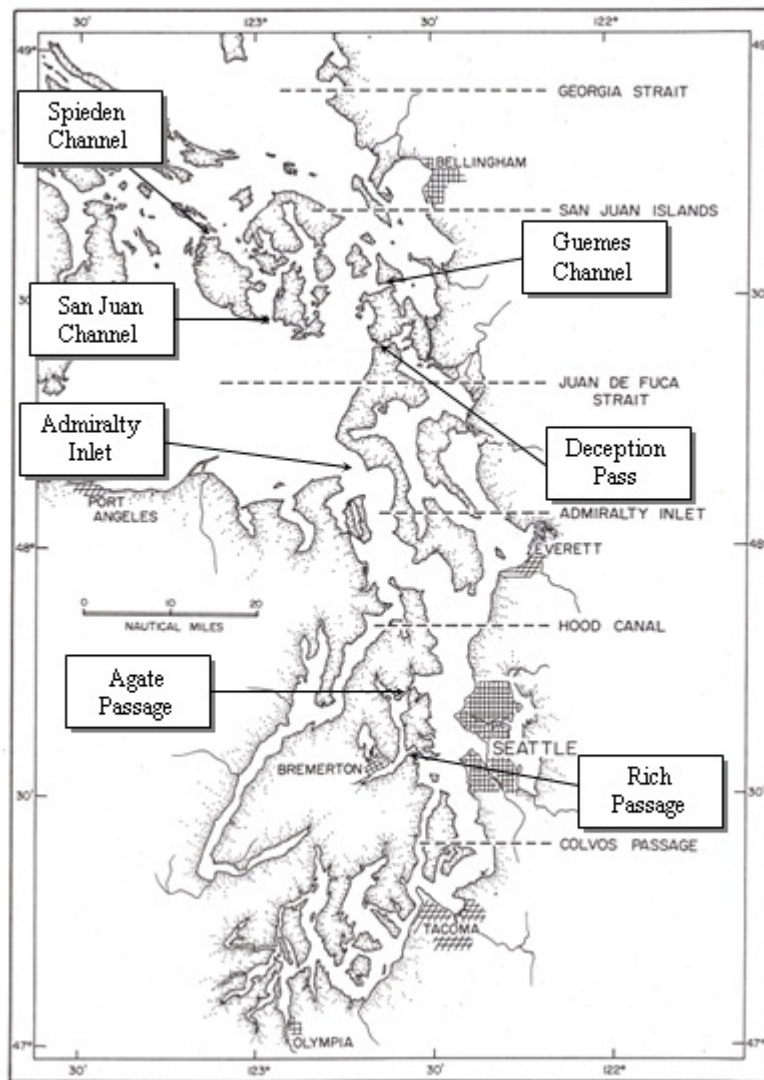
Golden Gate, San  
Francisco, CA  
<2 TWh/yr

Maine 7 Sites  
0.4 TWh/yr

Muskeget Channel  
Massachusetts  
0.1 TWh/yr



# Puget Sound - Washington



# Puget Sound Resource Summary

	Resource Size (MW)	Extraction Limit	Resource Intensity (kW/m <sup>2</sup> )	Eddies/Turbulence	Flow Directionality	Average/Max Depth (m)	Seabed	Interconnection	Maritime Use	Nearest Port Facility	
Northern Admiralty Inlet	180 MW	Fluid flow	0.6 kW/m <sup>2</sup> (hot spots)	Eddies outside project area	Bi-directional	60/90 m	Cobbles, gravel, sand, bedrock (?)	115 kV	Shipping, Ferry, Navy, Fishing, Diving	Everett, Port Angeles	Data Gaps
Bush Point	140 MW	Fluid flow	0.4 kW/m <sup>2</sup>	Billows	Elliptical	90/130 m	Cobbles, gravel, sand	115 kV	Shipping, Fishing	Seattle, Everett	Problem
Deception Pass	26 MW	Fluid flow, Space	5.5 kW/m <sup>2</sup>	Strong eddies	Bi-directional	25/40 m	Bedrock	115 kV	Diving	Anacortes, Everett	Caution
Guemes Channel	35 MW	Space	1.5 kW/m <sup>2</sup> (estimate)	Eddies outside area	Bi-directional	15/25 m	Rocky sediments	115 kV	Oil tankers, Ferry	Anacortes, Everett	Caution
Rich Passage	9 MW	Space	0.9 kW/m <sup>2</sup>	Eddies outside area	Bi-directional	15/30 m	Gravel and sand	12.5 kV	Navy, Fishing	Bremerton	Proceed
Agate Pass	3 MW	Space	1.5 kW/m <sup>2</sup>	Eddies outside area	Bi-directional	6/10 m	Gravel and clay	115 kV	Fishing, Diving	Bremerton	Proceed
Spieden Channel	56 MW	Electrical	0.6 kW/m <sup>2</sup>	Eddies outside area		70/125 m	Gravel (little data)	12.5 kV	Fishing, Ferry	Fri Harbor, Port Angeles	Proceed
San Juan Channel	45 MW	Space, Electrical	0.6 kW/m <sup>2</sup>	Eddies in shallows		60/135 m	Gravel (little data)	12.5 kV	Fishing	Fri Harbor, Port Angeles	Proceed

# Extractable Resource

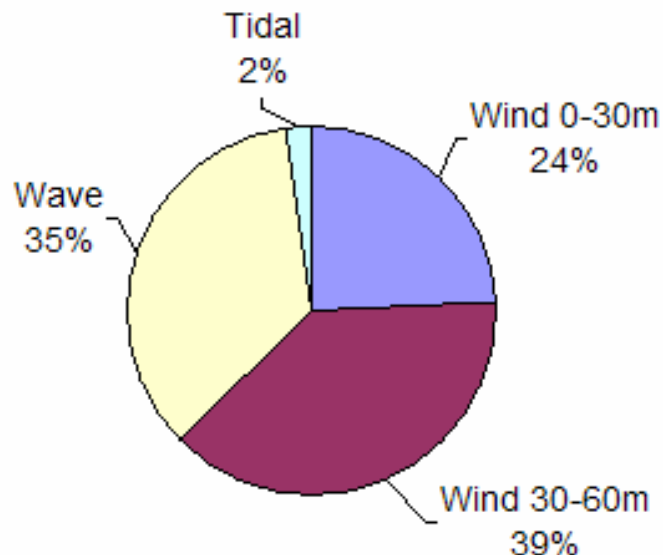
- Extraction Limits for tidal power are a function of available space within an area of interest and available resource
- New research indicates that extraction limits are a function of total power available within an estuary
- 15% extraction is used for this assessment, but limits are likely much higher (factor 3 – 10)

Primary Kinetic Energy	6 TWh
Extractable Energy (15%)	0.9 TWh
West Coast Annual Electricity Demand	376 TWh
% of electric production from tidal power	< 1%

# Confidence in Resource Estimates

	Wave	Tidal	Wind	
<b>Primary Resource Potential</b>	High	Medium	High	
<b>Technical Extractable Limit</b>	Medium	Low	High	
<b>Practical Extractable Limit</b>	Medium	Low	Low	

# Summary – U.S. Wave and Current Energy Resource



## Assumptions

**Ocean Wave** - 15% of incident wave energy; Wave climate 10kW/m or better; excluding Bering Sea.

**Tidal Current** estimated from aggregate siting studies; 15% extraction permitted – could be significantly larger; Significant further work is needed to define extractable potential.

**Offshore Wind** estimated from NREL studies. Assumes deployment density of 5MW/km<sup>2</sup>

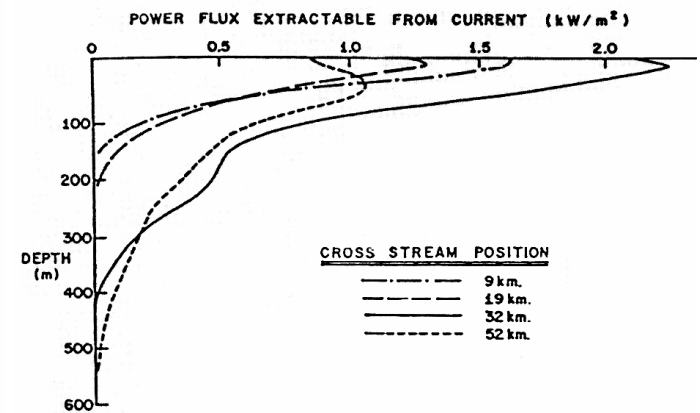
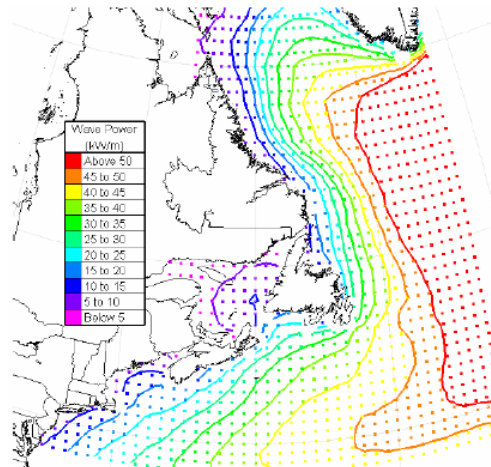
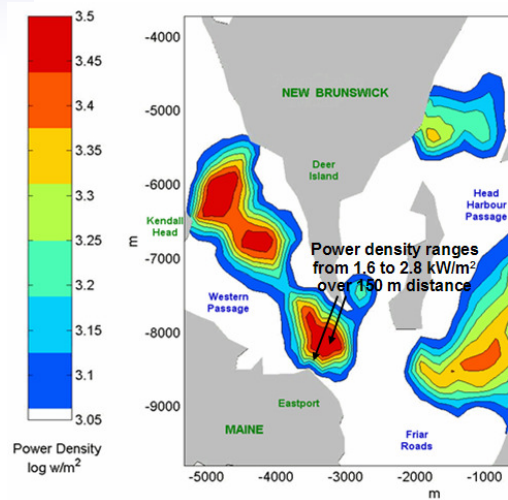
Total Generation Potential = 186 TWh/year => 21 GW average electrical power

Total Electricity Production CA,OR,WA => 43GW average electrical power

Resource Potential is about 50% of current electrical production

Deep-water offshore wind could add another 1000TWh/year to this

# Thank you



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